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Progress Report
VISUAL PERCEPTION OF DEPTH-FROM-OCCLUSION: A NEURAL NETWORK MODEL

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Two major goals have been accomplished during our first year of funded research. First, we have developed an environment for simulating neural systems, called NEXUS. NEXUS is designed for studying large networks. Towards this end, it is based on the principles of topological map organization, and introduces a novel network construct, programmable generalized neural (PGN) units. A single PGN unit can emulate the behavior of an entire neural circuit or assembly, allowing complex systems to be simulated. NEXUS is window-based and features an intuitive graphical user interface. Our second goal has been the development of a model of how the cortex extracts depth-from-occlusion. The model utilizes a multi- distributed representation of depth and emphasizes how object segregation and discrimination occur. The model shows how spatially separated portions of an occluded object can be dynamically linked in mental representations (e.g. the moon viewed through tree branches is perceived as an intact circular disc, not as separate pieces). Early tests also indicate that the model will fully account for the variations in the vividness of perception of a wide range of illusory (Kanizsa) contours. The model is currently being simulated and tested using NEXUS.

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DESCRIPTION OF MOST SIGNIFICANT FINDING

The Development of the NEXUS Neural Simulation Environment

Our work is concerned with developing a physiologically-based model of how the visual system generates depth-from-occlusion. Our overall goal is to construct a new theory of object discrimination that centers on the ability of the cortex to detect occlusion relationships, but which also accounts for a wide range of psychophysical effects including many of the classic Gestalt phenomena such as illusory contours. The key requirement for our studies is the ability to simulate multiple, interconnected areas of the mammalian cerebral cortex. We describe here progress towards the construction of a new type of neural simulator, which we call NEXUS, that allows the simulation of extremely large scale (105 cells and 106 connections) neural networks.

Although several neural simulators are presently available to the computational neuroscience community, none have the flexibility, ease-of-use, or scale-up properties required for our ongoing project. The major constraint on any simulation is depth of computation--with currently available computational resources it is not possible to accurately model very large networks at the synaptic level. One way around this problem is to use parallel computers, and in this regard we are in the process of adapting our simulator to run on a Connection Machine. However, NEXUS has three novel features that allow large networks to be simulated on conventional serial machines.

The first novel aspect of NEXUS takes advantage of the dominant structural feature of the vertebrate cortex, namely, map organization. NEXUS allows the user to create multiple neural maps and to interconnect them according to any desired anatomy. The computational power of parallel heterarchical maps can then be used for whatever functional specialization is desired. Since the pattern of connectivity in a map is locally uniform (subject, of course, to natural variability and noise), a tremendous savings in memory can be achieved by storing connections at the level of maps, rather than for each individual unit. Furthermore, memory is dynamically allocated in NEXUS in such a way that the majority of connection information required by a unit is stored in close physical proximity, thus increasing the efficiency and speed with which the computation is carried out.

The second novel feature of NEXUS involves the use of a powerful new type of structure as the fundamental unit of the simulation. PGN units (Programmable Generalized Neural units) take the place of model neurons in conventional simulations. PGN units can be used to model various levels of neural structure, from single cells to local circuits to more complex operations carried out by large assemblies of neurons. In conventional simulators, each neuron is represented by a set of equations that describe, at some level of accuracy, the current flows into and out of various segments of the cell. PGN units have a more

general capability of directly executing segments of programming code, so that any logical, evaluative, or operational function can be carried out as well as providing direct access to memory. This increase in level of abstraction provides a dramatic savings in computation time and memory. PGN units are particularly attractive in situations where the exact nature of the underlying neural operation is unknown (so modelling at a fine level of detail is useless), yet the computational nature of the problem is intense, requiring masses of cells each performing simple operations. In these cases, a single PGN unit can replace a whole hierarchy of conventional units. In addition to such higher-level functions, PGN units can also carry out more typical cellular or network type operations (such as scaling and adding inputs, thresholding, and computing output functions). Thus, one has the option of designing a system which, in different maps, the individual units are modelled at any level between neurons and assemblies.

The third novel feature of NEXUS is the ability to simulate connectionist, Hopfield, backpropagation or other applied neural networks <u>in addition to</u> biologically-based networks (for which it is chiefly designed). This flexibility allows the user to create <u>hybrid</u> networks, such as a visual processing system with a biologically-based early vision "front-end" hooked to a higher-level associative memory network based on backpropagation.

One possible objection to the present scheme is that NEXUS is not a true neural network since the PGN units are capable of carrying out sophisticated logical commands and operations. Our response is two-fold. First, the simple thresholding and summation properties used in conventional neural network models fall short of the capabilities of biological neurons. And purists can still use NEXUS to conduct such conventional network simulations, in an efficient and easy-to-use format as well. Second, our goal is to <u>simulate</u> biological neural networks, and this does not require that artificial neural networks be used--any technique which will allow more detailed and larger-scale simulations is an innovation. One should not get caught in a semantic trap of thinking the only way to capture a behavior is by direct mimicry, the concept of homology in evolution certainly stands out as a potent example.

As documented in the accompanying report, the simulator is written in C and features an easy-to-use graphical user interface. Large, complex networks can be specified with just a few lines of input (which specify things such as number of networks, types of units, desired physiolgical parameter values, which unit types are connected to which others, etc.). Several options are available for stimulation paradigms, perhaps the most useful is a simple bit-mapped input routine that accepts any 2-dimensional grey-scale pattern at each point in time. Results are displayed on the screen in terms of color coded 2-D representations of each network, with a variety of options available for presentation.

POTENTIAL SCIENTIFIC AND TECHNICAL SIGNIFICANCE

The major scientific significance of NEXUS is that it allows multiple interconnected cortical networks to be simulated together and their interactions studied. Given the vast and intricate pattern of interareal cortical connections, such a capability is necessary to ask the basic questions of how cortical integration takes place.

The major technical significance of NEXUS is that it allows the simulation of large-scale neural networks in reasonable computation times at a flexible level of biological detail. NEXUS will allow a large group of users to carry out accurate simulations of a wide range of neural structures with a bare minimum of start-up time. Since the simulator is written in C, is based on the UNIX operating system, and uses public graphics programs, it should be portable to any current workstation.

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